ing and administration costs. All of the societies maintain some sort of public activity. The Historical Association, and (since the date of this report), the Political Association, have moved in the same direction.

The net expenditure varies from $30,000 for the Academy to $4,000 for the Political Science Association. The measure of the effectiveness of these societies is however not the sums spent but the value of the work done. The Academy, with $30,000 a year to spend, ought certainly to be lending a far greater aid to the problems of the general subject of history, government and economics than the three other societies with their combined income of $27,000. How far that is the case must be left to the decision of those cognizant of the work of the four societies. One thing is certain, that none of the four societies furnishes a sufficiently detailed account; and that the report of the American Academy of Political and Social Science shows over $20,000 a year expended for publications as against $18,000 for the publications of the other three societies. The published accounts do not furnish a basis from which it is possible to find out why its cost per unit for carrying on and printing the publication should be twice as great as those of all the three sister societies doing the same kind of work. Here is an opportunity for a reform in corporate accounts.

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SPECIAL ARTICLES

EVIDENCE THAT SODIUM BELONGS TO A RADIOACTIVE SERIES OF ELEMENTS

By the usual test for radioactivity, *i. e.*, the continued ionization of a gas independent of other physical conditions, sodium as an element does not display any activity that is definitely greater than that found in all matter. And the ionizing activity of ordinary matter is so slight that it can not be stated with definiteness whether or not it is of itself radioactive. But radioactivity implies a more fundamental change than that of emitting matter and energy continuously. It implies an atomic disintegration. If α particles are emitted the atoms go by leaps and bounds to new atoms of other properties, while if β and γ radiations are emitted the wearing away of the atoms must be just as certain, though no one has been able to conjecture by what steps the change might take place.

Campbell and Wood[1] examined the sodium compounds for ionizing radiations. Their apparatus would have detected an activity much less than that of potassium, which is only one thousandth that of uranium. No radiations could be measured. The fact that a given element does not give out a measurable ionizing radiation is not necessarily evidence that it is not radioactive. For example, we may note the case of radium *D*, which gives no measurable radiations. Yet it disintegrates to half value in about forty years. It is therefore known as a radioactive element. Further, helium as an element may be classed as a radioactive element, providing all helium is of radioactive origin, although of itself no ionizing radiations are emitted. It is sufficient that an element be of radioactive parentage. Thus sodium is a radioactive element if it can be shown that it disintegrates into other forms of matter or if it is the result of the disintegration of other forms of matter.

If sodium is a radioactive element we may at present look for other evidence than direct radiations. We shall inquire if in past geologic time sodium has accumulated radioactivity from other matter, or, on the other hand, if sodium has disappeared or disintegrated into other forms of matter.

THE EVIDENCE FROM GEOLOGY

Geophysics furnishes two distinct lines of evidence which favor the hypothesis that sodium belongs to a series of radioactive elements. The first is based on the age of the earth as determined by radioactive data and by the accumulation of sodium in the ocean. The second is based on the relative accumulation in the ocean of sodium compared to chlorine, taken in connection with the relative

[1] *Proc. Camb. Phil. Soc.*, 14, p. 15.

annual output of these two elements by the rivers.

Different authorities give the age to range between seventy and one hundred million years. On the other hand, the data of radioactivity require the age to be about ten times as great as the figures above noted. The principles of the radioactive method are based on the determination of the amounts of helium or lead associated with known quantities of uranium found in rocks of different epochs. The two principal assumptions that are involved are that during the age in question the amount of the uranium and its products which give rise to helium shall have remained constant and that the rate of production of helium shall have remained unchanged. Naturally these two assumptions can not be proved. It can only be said that there is no evidence that casts much suspicion on these. However, in all determinations by the radioactive method some error may accrue owing to a simultaneous deposition of uranium and lead and helium at the time of formation of the rock whose age is in question. As may seem clear later in this discussion, the magnitude of this error is probably not greater than the discrepancy between the age as determined by the accumulation of helium and by the accumulation of lead.

According to experiments by Rutherford and his colleagues one gram of uranium in equilibrium with its products gives 10.7×10^{-8} c.c. of helium per year. Now if we examine the rocks of the different geological epochs we find the rare gas helium enclosed in the rock wherever uranium is found, and further the older the rocks the greater is the amount of the helium associated with each gram of the uranium. Obviously, if we divide the total amount of helium per gram of uranium by the above constant, 10.7×10^{-8}, we obtain the number of years during which the uranium has been depositing helium, *i. e.*, the age of the rock containing the uranium. It may be mentioned that the diminution of the amount of uranium during the age in question is so small that it may be considered negligible in comparison with other errors.

Perhaps the greatest chance for error in the above method of calculation lies in the possible escape of helium from the rock containing the uranium. If so the age of the rock as calculated might be too small. The method would therefore set a minimum limit on the age of the earth.

But if we accept Boltwood's conclusion that the lead associated with uranium in rocks resulted from the radio-active disintegration of the uranium series of elements, and that one gram of uranium gives rise to 1.88×10^{-11} gram of lead per year, we have a check upon the results obtained based on the helium deposits. In general the lead deposits give a somewhat larger age for a given rock than do the helium deposits, which is what we should expect if the helium may escape or if lead might have been deposited with the uranium originally.

Using the method outlined above, Rutherford, in 1906, found the age of a sample of fergusonite to be 240,000,000 years. This was deduced as outlined from the fact that 1.81 c.c. of helium was taken from one gram of the mineral known to contain about 7 per cent. uranium.

Strutt by the same method found two rocks of the Archæan period from Quebec to be 222 and 715 million years old, and two of the same kind from Norway to be 213 and 449 million years old. He also found the average minimum value for hæmatite of the Eocene period to be 31 million years, the same for the carboniferous period limestone to be 150 million, while for the Archæan age the average was 710 million years.

Holmes[2] using as a basis the ratio of the lead to the uranium in the rocks found the values given in the following table:

Period	Age	
Carboniferous	340,000,000	years.
Devonian	370,000,000.	
Pre-Carboniferous ..	410,000,000.	
Silurian	430,000,000.	
Pre-Cambrian ...	1,025,000,000	Sweden.
	1,310,000,000	U. S.
	1,640,000,000	Ceylon.

[2] *Roy. Soc. Proc.*, Ser. *A*, 85, p. 248, 1911.

The above results show that the earth in its present form must be many times a hundred million years old.

However, if we take the evidence as based on the result that is obtained by dividing the total amount of sodium in the ocean by the annual additions of all the rivers of the globe, we find that the age of the ocean can not be more than one hundred million years. Two of the most eminent geologists, F. W. Clarke[3] and J. Joly,[4] think 70,000,000 years to be more nearly the correct age. It seems to me that these estimations were not made without due consideration of the largest sources of error. According to Clarke the saline matter of the ocean if segregated would occupy nearly five million cubic miles, a quantity compared to which all beds of rock salt become insignificant. He also considered the salt of marine origin in sedimentary rocks and he figured that a correction of not more than one per cent. was necessary to allow for sodium disseminated in this way. If there is error due to unequal annual additions by the rivers, Becker[5] argues that it is altogether in favor of making the age of the earth yet smaller rather than larger, perhaps between 50 and 70 million years. There is therefore a discrepancy between the age of the earth as deduced by the two methods. Joly in the *Philosophical Magazine* for September, 1911, favors the view that the radioactive constants are in error, because these constants have not been taken from data extending over a sufficiently long time and under proper circumstances free from doubtful assumptions.

I wish to suggest that there is another explanation of the discrepancy that requires no distrust of the radioactive constants as they have been experimentally determined. In fact, the explanation is merely an extension of our knowledge in radioactivity. The discrepancy may be made to disappear if sodium is supposed to belong to a series of radioactive elements. If we accept the present data of radioactivity as authoritative, then it must be admitted that there is not enough sodium in the ocean. Perhaps during geologic time elements of higher atomic weight may have been disintegrating into sodium, and therefore the annual output of the rivers now is not the same as the average annual output for all time in the past. That is, the sodium over the land has been increasing by radioactive production while sodium in the ocean has been increasing almost entirely by the annual river supply. This would necessitate that the parent of sodium should commonly exist in relatively insoluble compounds. Otherwise we should have had sodium produced radioactively also in the ocean, and perhaps sodium deposits in the bottom of the ocean. The above fact should give us some clue as to the parentage of sodium, if our whole argument is not faulty. Obviously those elements that have been deposited in the ocean bed in appreciable quantities are eliminated.

The second way for explaining the small sodium content of the ocean is to assume that the sodium in the ocean has disintegrated into other elements. The theory of radioactivity as it now stands, however, requires that the rate of decay of an element shall not be altered by its physical state or surroundings. Then it is highly probable that the sodium in the ocean has not decayed faster than has the sodium on the land, and therefore any diminished quantity of sodium on the ocean would have been offset by a diminished annual addition of the rivers. But the quantity of sodium carried by the rivers is not known to vary greatly with the amount in the earth's crust. It seems then that this second explanation is within the limits of possibility.

The simplest explanation and one which requires no apologies or additional assumptions is based on the supposition that the sodium on the land has been increasing by virtue of the existence of the parent of sodium there and the non-existence of the parent in the ocean or the ocean bed. Perhaps there would be less chance for error if it were stated that the pres-

[3] Bulletin 491, U. S. Geol. Surv.

[4] *Phil. Mag.*, Ser. 6, 22, p. 357, 1911.

[5] *Quart. Journ. Sci.*, May, 1909.

ence of sodium must have existed more abundantly on the land. This is along the lines of recent progress, and it is particularly favored because it is the only apparently reasonable explanation for another discrepancy arising from the facts of geochemistry. This additional discrepancy is involved in the succeeding paragraphs.

FURTHER EVIDENCE FROM GEOLOGY INDICATING THAT SODIUM BELONGS TO A SERIES OF RADIOACTIVE ELEMENTS

There are other elements carried to the ocean by the rivers in a soluble state, which indicate quite a different age of the earth, and consequently favor the radioactivity of sodium. Only those elements that are not deposited in the ocean bed or otherwise removed from the ocean water may be considered for reliable information. Clarke in his "Geochemistry," second edition, p. 125, gives the following facts; the figures in the last column are my own deductions however.

	Annual Output from Rivers, Metric Tons	Metric Tons in the Ocean	Age of the Ocean
Chlorine ...	$155,350\times10^3$	$25,536\times10^{12}$	160×10^6
Sodium......	$158,357\times10^3$	$14,136\times10^{12}$	89×10^6

The geologists do not believe that the rivers carried any less chlorine or sodium formerly than they do now. In fact, Becker thinks that they must have carried more previously than they do now. But supposing they did carry less sodium in previous ages (in order to explain away the discrepancies on the age of the earth), there is no obvious reason why they should not also have carried proportionately less chlorine. We may, therefore, for checking purposes, say nothing concerning the annual river output further than it should have varied alike with sodium and chlorine. On this assumption the above figures show that there is not as much sodium in the ocean as there should be. Disregarding the radioactivity data for the uranium series of elements altogether, we see that the above evidence favors radioactivity of sodium. Clarke goes on further to state:

> We can understand the accumulation of sodium in the ocean and some of the losses are accounted for, but the great excess of chlorine in sea water is not easily explained. In average sea water sodium is largely in excess of chlorine; in the ocean the opposite is true, and we can not help asking whence the halogen element was derived. Here we enter the field of speculation and the evidence upon which we can base an opinion is scanty indeed.

This excess of chlorine can be accounted for by the same hypothesis that was used to explain the discrepancies in the age of the earth in the early part of the paper, viz., sodium has either accumulated radioactively on the land or disintegrated in the ocean, while for chlorine either these changes have not taken place or else they have gone on at a rate much slower than that in sodium.

From the foregoing, it is obvious that, whether we consider the radioactive data or only the data of geochemistry, either method of approach makes it convenient to assume that sodium belongs to a radioactive series of elements. There has not been to my knowledge any satisfactory explanation for the discrepancies to which attention is called in this paper, either singly or in common. However, it may be noted that the age of the earth as calculated from the chlorine content of the ocean is yet much smaller than that given by the radioactive data, but I do not believe this to be seriously against the argument as presented. It may be that chlorine is accumulating slower than sodium on the land, or perhaps all matter is radioactive in varying degrees, but that is beyond the argument here presented.

It seems worth while to inquire further what elements of atomic weight greater than that of sodium are found more abundantly on land than in the ocean. If our hypothesis is correct we might obtain a list of elements one or more of which should give rise to sodium. And a further study of this list, both in nature and in the laboratory, might reveal the parent of sodium. Of course if the parent of sodium had long ago become extinct this search would be futile.

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